EARTH PULSATIONS.

BY

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For many years philosophers have speculated as to whether the surface of the earth is really so stable as it usually appears. With the sudden and violent motions of our soil which we call Earthquakes man has been familiar since the earliest times, and the origin of these disturbances have always formed a fruitful source of speculation. With the help of properly constructed instruments, our knowledge of the nature of these movements has during the last few years been greatly extended, and we are brought to the conclusion that these natural vibrations are propagated through the surface of our earth in a manner very different to that which we should have anticipated from our knowledge of elastic solids. Another order of earth movements which in the hands of Timoteo Bertelli of Florence, M. S. di Rossi of Rome and other Italian investigators have recently received considerable attention are Earth Tremors. From observations carried on in Italy during the past 10 years it would appear that the soil of that country is practically in a perpetual state of vibration even in districts far removed from volcanic centers. On account of the small amplitude of these motions, they are only to be observed with aid of specially constructed instruments. Messrs. George and Horace Darwin in connection with their experiments on the disturbance of gravity caused by lunar attraction have shown that these movements are common to the soil of Britain. Like observations have been made in Japan and it does not seem improbable that after farther experiments have been carried out we shall be brought to the conclusion that the surface of the whole globe is affected with similar microseismical disturbances.

In addition to these minute movements which escape the attention of the ordinary observer on account of the smallness of their amplitude, theoretical investigation has also shewn us that there may be existing in the soil on which we live movements which have escaped our attention on account of the slowness of their period. For want of a better term I call these motions Earth Pulsations. Mr. George Darwin in his last report to the British Association has shewn that movements of this nature may be produced by barometrical variation. A rise of the barometer over an area is equivalent to loading that area with a weight, in consequence of which it is depressed. When the barometer falls, the load is removed from the area, which in virtue of its elasticity rises to its original position. This fall and rise of the ground, completes a single pulsation.

On the assumption that the earth is as rigid as steel Mr. Darwin calculates that if the Barometer rises an inch over an area like Australia, the load is sufficient to sink that continent 2 or 3 inches.

The tides which twice a day load our shores cause the land to rise and fall in a similar manner. On the shores of the Atlantic, Mr. Darwin has calculated that this rise and fall of the land may be as much as 5 inches. By these risings and fallings of the land the inclination of the surface is so altered that the stile of a plummet suspended from a rigid support ought not always to hang over the same spot. There would be a deflection of the vertical.

In short, calculation respecting the effects of loads of various descriptions which we know are by natural operations continually being placed upon and removed from, the surface of various areas of the earth's surface, indicate that slow pulsatory movements of the earth's surface must be taking place, causing variations in inclination of one portion of the earth's crust relatively to another. That pulsatory motions of this description have also been observed it may be shewn that there is but little doubt. The magnitude of these disturbances however is so great, that we can hardly attribute their origin solely to the causes which have just been indicated.

Rather than seek an explanation from agencies exogenous to our earth we might perhaps with advantage appeal to the endogenous phenomena of our planet. When the barometer falls which we have shewn corresponds to an upward motion of the earths crust, we know from the results of experiment that microseismic motions are particularly noticeable.

As a pictorial illustration of what this really means, we may imagine ourselves residing on the loosely fitting lid of a large cauldron, the relief of the external pressure over which, increases the activity of its internal ebullition—the jars attendent on which are gradually propagated from their endogenous source to the exterior of our planet. This traveling outwards would take place much in the same way that the vibrations consequent to the rattle and jar of a large factory slowly spread themselves farther and farther from the point where they were produced.

Admitting an action of this description to take place, it would then follow that this extra liberation of gaseous material beneath the earth's crust would result in an increased upward pressure from within, and a tendency on the part of the earth's crust to elevation. If we accept this as an explanation of the increased activity of a tremor indicator, then such an instrument may be regarded as a barometer, measuring by its motions the variations in the internal pressure of our planet.

The relief of external pressure and the increace of the internal pressure it will be observed both tend in the same direction, namely to an elevation of the earth's crust.

This explanation of the increased activity of earth tremors which I believe is one suggested by M. S. di Rossi, is only advanced as a speculation—more probable perhaps than many others. We know how a mass of sulphur which has been fused in the presence of water, in a closed boiler, gives up in the form of steam the occluded moisture upon the relief of pressure. In a similar manner we see steam escaping from volcanic vents and cooling streams of lava. We also know how gas escapes from the pores and cavities in a seam of coal on the fall of the barometrical column. We also know that certain wells increase the height of their column under like conditions. The increase in the quantity of water flowing from an area consequent on diminution of atmospheric pressure, may, by rendering an area of less weight, facilitate its rise.

The next question is as to whether we have direct evidence of such heavings and sinkings in our earth's crust, the possibility of which has here been indicated.

Although some of the proofs which are brought forward to show that slow pulsations like these have been repeatedly observed, are unsatisfactory, taking them one with another they indicate that these pulsatory phenomena have a real existence.

Pendulums for instance which have been suspended for the purposes of seismometrical observations, have both by observers in Italy and Japan been seen to have moved a short distance out from, and then back to, their normal position.

This motion has simply taken place on one side of their central position and is not due to a swing. The character of these records is such, that we might imagine the soil on which the support of the pendulum rested, to have been slowly tilted and slowly lowered. They are the most marked on those pendulums provided with an index writing a record of its motions on a smoked glass plate,—the index being so arranged that it gives a multiplied representation of the relative motion between it and the earth. As motions of this sort might be possibly due to the action of moisture in the soil tilting the support of the pendulum and to a variety of other accidental causes, we can not insist on them as being certain indications that there are slow tips in the soil, but for the present allow them to remain as possible proofs of such phenomena.

Evidence of displacement of the vertical which are more definite than the above are those made by Bertelli, Rossi, Count Malvasi and other Italian observers, who whilst recording earth tremors have spent so much time in watching the vibrations of stiles of delicate pendulums by means of microscopes. As a result of these observations we are told that the point about which the stile of a pendulum oscillates, is variable.

These displacements take place in various azimuths, and they appear to be connected with changes of the barometer.

From this and from the fact that it is found that a number of different pendulums differently situated on the same area give similar evidence of these movements, it would hardly seem that this phenomena could be attributed to changes in temperature, moisture and the like. M. S. di Rossi lays stress on this point especially in connection with his microseismograph, where there are a number of pendulums of unequal length which give indications of a like character. The direction in which these tips of the soil take place, which phenomena are noticeable in seismic as well as microseismic motions, Rossi states are related to the direction of certain lines of faulting.

Bubbles of delicate levels when examined by a microscope change their position with meteorological variations, but Rossi also tells us that they change their position, sometimes not to return for a long time during a microseismic storm. Here again we have another phenomena pointing to the fact that microseismic disturbances are the companions of slow alterations in level. The more definite kind of information which we have to bring forward, tending to prove the existence of earth pulsations too slow in period, to be experienced by ordinary observers, are those which appear to be resultant phenomena of great earthquakes.

The phenomena that we are certain of, in connection with earth vibrations, whether these vibrations are produced artificially by explosions of dynamite in bore holes, or whether they are produced naturally by earthquakes, are, firstly that a disturbance as it dies out at a given point often shows in the diagrams obtained by seismographs a decrease in period, and secondly, a similar decrease in the period of the disturbance takes place as the disturbance spreads.

As examples of these actions I will refer to the diagrams which I have given in a paper on the Systematic Observation of Earthquakes in Vol. IV of the Transactions of the Seismological Society of Japan.

In a diagram of the disturbance of March 1st 1882 it seems that the vibrations at the commencement of the disturbance had a period of about 3 per second, near the middle of the disturbance the period is about 1.1 whilst near the end the period has decreased to .46. That is to say the back and forth motion of the ground at the commencement of the earthquake was 6 times as great as it was near the end, when to make one complete oscillation it took between 2 and 3 seconds. Probably the period became still less, but was not recorded owing to the insensibility of the instruments to such slow motions.

We have not yet the means of comparing together continuous diagrams of two or more earthquakes, one having been taken near to the origin and the other at a distance. The only comparisons which I have been enabled to make have been those of diagrams taken of the same earthquake,—one in Tokio and the other in Yokohama. As this base is only 16 miles and the earthquake may have originated at a distance of several hundreds of miles, comparisons like these can be of but little value.

The best diagrams to illustrate the point I wish to bring forward, are those at the end of the above mentioned paper. These are the results obtained at three stations in a straight line, but at different distances from the origin of a disturbance produced by exploding a change of dynamite in a bore hole. A simple inspection of the diagrams here referred to, shows that at the near station the disturbance consisted of back and forth motions which as compared with the same disturbance as recorded at a more distant station were very rapid. Farther by examining the diagram of the motions say at the near station, it is clearly evident that the period of the back and forth motion rapidly decreased as the motion died out.

These diagrams are referred to, as examples out of a large series of other records, all showing like results.

Although we must draw a distinction between earth waves and water waves, we yet see that in these points they present a striking likeness. Let us take for example any of the large earthquake waves which have originated off the coast of South America and then radiated outwards, until they spread across the Pacific to be recorded in Japan and other countries perhaps 25 hours afterwards, at a distance of nearly 9000 miles from that origin. Near the origin they appeared as walls of water which were seen rapidly advancing towards the coast. These have been from 20 to 200 feet in height and they succeeded each other at rapid intervals, until finally they died out as gentle waves. By the time these walls of water traversed the Pacific, let us say, to Japan, they broadened out to a swell so flat that it could not be detected on the smoothest water, excepting along shore lines where the water rose and fell like the tide. Instead of a wall of water 60 ft. in height we had long flat undulations perhaps 8 ft. in height, but with a distance from crest to crest of more than 120 miles.

If we turn to the effects of large earthquakes as exhibited on the land, I think that we shall find records of phenomena which are only to be explained on the assumption of an action having taken place analogous to that which takes place so often in the ocean, or an action similar to that exhibited by small earthquakes and artificially produced disturbances greatly exagerated.

As a remarkable instance of such phenomena we may take the great earthquake of Lisbon (Nov. 1st 1755). In Spain, Northern Italy, the South of France and Germany, Northern Africa, Madiera and other Atlantic islands, the effects of the disturbance which created so much devastation in Portugal, were also more or less severely felt as violent movements of the soil.

In other countries further distant as for instance, Great Britain, Holland, Norway and Sweeden, and North America, although the records are numerous, the only phenomena which were particularly observed were the slow oscillations of the waters in lakes, ponds, canals &c. In some instances the observers especially remark that there was no motion in the soil.

Pebley Dam in Derbyshire which is a large body of water covering some 30 acres, commenced to oscillate from the South.

A canal near Godalmin flowed 8 ft. over the walk on the north side.

Coniston water in Cumberland which is about 5 miles long, oscillated for about 5 minutes, rising a yard up its shores. Near Durham a pond 40 yds. long and 10 broad rose and fell about 1 ft. for 6 or 7 minutes. There were 4 or 5 ebbs and flows per minute.

Loch Lomond rose and fell though about 2½ ft. every 5 minutes, and all other Lochs in Scotland seem to have been similarly agitated.

At Shirburn Castle in Oxfordshire where the water in some moats and ponds was very carefully observed, it was noticed that the floods began gently—the velocity then increased, till at last with great impetuosity they reached their full height. Here the water remained for a little while, until the ebb commenced at first gently but finally with great rapidity. At two extremities of a moat about 100 yds. long it was found that the sinkings and risings were almost simultaneous. The motions in a pond a short distance from the moat were also observed, and it was found that the risings and sinkings of the two did not agree. During these motions there were several maxima.

These few examples of the motions of waters without any record of the motions of the ground, at the time of the Lisbon earthquake, must be taken as examples of a very large number of similar observations of which we have detailed accounts.

Like agitations it must also be remembered were perceived in North America and in Scandinavia, and if the lakes of other distant countries had been provided with sufficiently delicate apparatus, it is not unlikely that like disturbances would have been recorded.

The only explanation for these phenomena appears to be that the short quick vibrations which had ruined so many cities in Portugal, had by the time they had radiated to distant countries gradually become changed into long flat waves having a period of perhaps several minutes, and in countries like England these pulse like movements were too gentle to be perceived excepting in the effects produced by tipping up the beds of lakes and ponds.

The phenomenon was not unlike that of a swell produced by a distant storm.

At Amsterdam and other towns, chandeliers in churches were observed to swing. At Harlem floods rose over the sides of tubs and it is expressly mentioned that no motion was perceived in the ground.

At the Hague a tallow chandler was surprised at the clashing noise made by his candles and this the more so because no motion was felt under foot.

At Toplitz the pulsations of the ground appear to have manifested themselves in effects upon the springs. The flow of the principal spring was greatly increased. Before this increase it became turbid and at one time stopped. Subsequently it became clear and flowed as usual, but the water was hotter and more strongly mineralized.

At one or two places as for instance in Britain slight earthquakes were experienced. These however were local and in every probability were secondary disturbances produced by the pulsations causing ground in a critical state to give way.

In this earthquake I think then, that we have a clear case of the production of pulsations in the soil too slow to be felt by ordinary observers.

Motions like these might be called slow earthquakes, and it is not unlikely that they are the resultants of all large disturbances. When they accompany a large earthquake like that of Lisbon, their cause is evident. But when we see the waters of lakes and ponds oscillating, the bulbs of levels disturbed, and the plumment line of pendulums displaced the reason of these phenomena is not so apparent. It would seem possible that in some cases pulsations producing these phenomena might have their origin beneath the oceans or deep down beneath the earth's crust. Perhaps instead of commencing with the snap and jar of an earthquake, they may commence as a heaving or sinking of a considerable area which may be regarded as an uncompleted effort in the establishment of an earthquake or a volcano. The very fact that volcanoes rising from deep oceans have in the first instance forced their way against a pressure of at least 3 or 4 tons to the square inch, indicates to us the existence of internal pressures tending to raise the crust of the earth which pressures are infinitely greater than any of the pressures which we have upon the surface of our earth produced by tides and variations in the barometrical column. If we follow the views of Mallet in considering that the pressures exerted on the crust of our earth may in volcanic regions be roughly estimated by the height of a column of lava in the volcanoes of such districts, we see that in the neighbourhood of a volcano like Cotopaxi the upward pressures must have been many times greater than the pressures already mentioned,—sea level being taken as the line of hydrostatic equilibrium. The chief point however, is that beneath the crust of our earth enormous pressures exist tending to cause eruption—and farther, that these are variable. Before a volcano bursts forth we would expect that there should be in its vicinity an upward bulging of the crust and after its formation, a fall. Farther it is not difficult to conjecture other possible means by which such pressures may obtain relief.

Should these pressures then find relief without rupturing the surface, it is not difficult to imagine them as the originators of vast pulsations which may be recorded on the surface of the earth as wave like motions of slow period, similar to the motions in the outer area of a tract disturbed by a destructive earthquake.

If slow undulatory motions or changes in the vertical do occur in the crust of the earth, whatever may be their origin, we have numerous phenomena which certainly admit of explanation on such an assumption.

In Switzerland from time to time we hear of oscillations in the waters of lakes known under the name of Rhussen and Seiches. These it may be remarked are common to the lakes and inland seas of many countries.

Other examples of what may have been a slow oscillating motion of the earths crust are referred to by Mr. George Darwin in his Report to the British Association in 1882.

One of them was made, by M. Magnus Nyrén at Pulkova who when engaged in levelling the axis of a telescope observed spontaneous oscillations in the bulb of the level.

This was on May 10 (April 28) 1877. The complete period was about 20 seconds, the amplitude being $1''.5$ and $2''$. One hour and 14 minutes before this he observes that there had been a severe earthquake at Iquique, the distance to which in a straight line was 10,600 kilometers and on an arc of a great circle 12,500 kilometers. On Sept. 20 (8) in 1867 Mr. Wagner had observed at Pulkova oscillations of $3''$, seven minutes before there had been an earthquake at Malta.

On April 4 (March 23) 1868 an agitation of the level had been observed by M. Gromadzki, five minutes before there had been an earthquake in Turkestan. Similar observations had been made twice before. These however had not been connected with any earthquakes—at least, Mr. Darwin remarks, with certainty. Like phenomena are mentioned by M. S. di Rossi in his Meteorologia Endogena.

Thus on March 20th 1881 at 9 P.M. a watchmaker in Buneos Ayres observed that all his clocks oscillating North and South suddenly began to increase their amplitude, until some of them became twice as great as before. Similar observations were made in all the other shops. No motion of the earth was detected. Subsequently it was learnt that this corresponded with an earthquake in Santiago and Mendoza.

Another remarkable example illustrating the like phenomena is the observation which was made on Dec. 21 1860, by means of a barometer in San Francisco, which oscillated with periods of rest for ½ an hour. No shock was felt, nor is it likely that it was a local accident as it could not be produced artificially. On the following day however a violent earthquake was experienced at Santiago.

This brings me to the end of the few important illustrations of the phenomena of Earth Pulsations which I have at my disposal. With a little trouble I have no doubt that these might be greatly multiplied. As they stand however I think that they are quite sufficient to convince us of the existence of phenomena which hitherto have been almost entirely overlooked. That disturbances of the vertical are from time to time produced by long pulse like waves can hardly be doubted. These however are phenomena of a different order to those which were so carefully sought for by the Darwins at Cambridge.